ECE 595
Network Economics
WNP - Chapter 1

UNM
Electrical & Computer Engineering

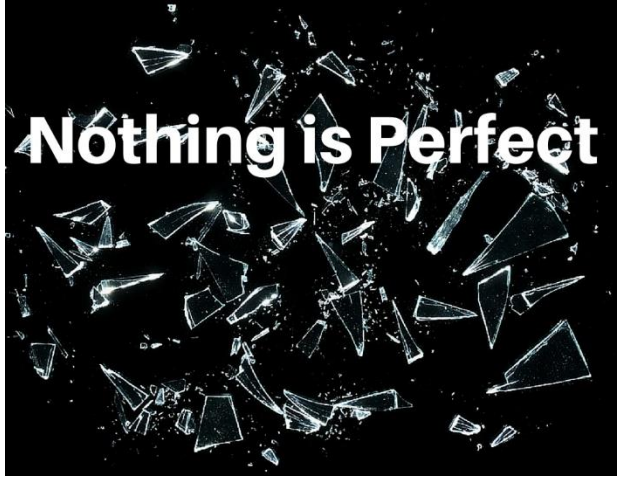
Why Network Economics?

- Wireless Communications & Networking Practices: tightly coupled with economic considerations – almost impossible to make a sound technology choice without understanding the corresponding economic implications.

Our Goal

- provide a fundamental introduction on how microeconomics and pricing theory can help us to understand and build better wireless networks
- How pricing mechanisms influence the fast growing modern wireless industry
- Basics of wireless communication technologies and microeconomics
- Social optimal pricing, monopoly pricing, price differentiation, oligopoly pricing, network externalities
- Introductory discussion of convex optimization and game theory
- Wireless applications: wireless video streaming, service provider competitions, cellular usage-based pricing, network partial price differentiation, wireless spectrum leasing, distributed power control, cellular technology upgrade

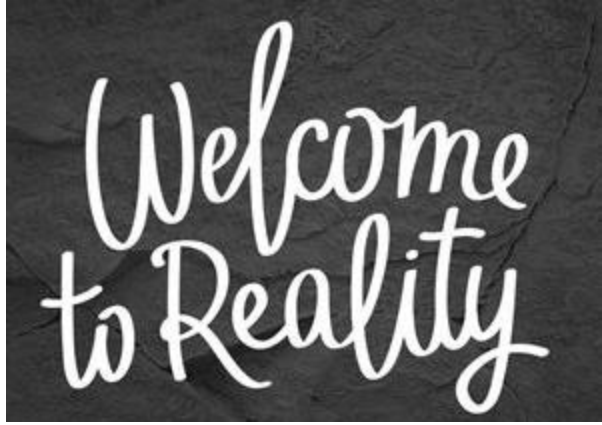
Wireless Utopia



- Unlimited wireless spectrum
- The wireless technologies can provide a communication speed comparable to wireline networks
- Heterogeneous wireless technologies co-exist perfectly without mutual interference
- Wireless users have reasonable demands that can always be satisfied without overburdening the network
- Wireless service providers aim to maximize the social welfare instead of their own profits

In such a perfect world, there would be no reason to worry about economic issues…

Wireless Reality



- The wireless spectrum is very limited and crowded
- The communication speed of the latest wireless technologies is nowhere close to that of wireline networks (except for some very short distance wireless communications)
- Heterogeneous wireless networks often exist with little or no coordination
- Heavy mutual interference between networks and devices are the norm rather than the exceptions
- The exploding growth of wireless data traffic is far beyond the growth of wireless capacity
- The wireless service providers often care more about profits than social welfare.

How will we address the wireless reality?

- Advance of wireless technologies
- Economic innovations
- Policy reforms

Economics can help to improve

- The overall performance of the wireless networks
- The satisfaction levels for both users and service providers

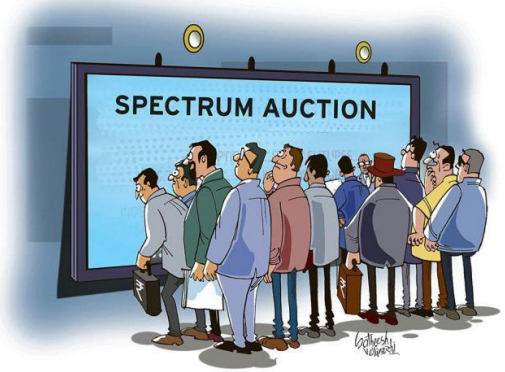
Regulating the Spectrum

- One key reason for studying wireless network economics is to resolve the tension between limited wireless resource supplies and the fast growing wireless demands.
- The radio spectrum is limited…part of it used for wireless communications!!!
- Wireless spectrum: a tightly controlled resource worldwide
- The traditional way of regulating the spectrum is the ***static licensing approach***, which assigns each wireless application a particular piece of spectrum at each particular location.
- All spectrum licenses belong to government identities and commercial operators.
- Frequency allocation map of every country or region.

BUT

- New wireless technologies and services are emerging rapidly.
- Every new wireless commercial service, from satellite broadcasting to wireless local-area network, has to compete for licenses with numerous existing sources, creating a state of spectrum drought

Spectrum Auction



- A key challenge for government regulators is how to allocate these ever decreasing and precious spectrum resources wisely to achieve the maximum benefits for society.
- Spectrum auction has been advocated and successfully implemented in many countries.
- This will help to allocate the spectrum to service providers who value the resources most, as these providers are typically the ones who have the best technologies and thus the capability to provide the maximum benefits to the customers.

Dynamic Spectrum Management

- Revolutionary approach: enable unlicensed wireless users to opportunistically share the spectrum with licensed users through dynamic spectrum management.
- Motivation: many licensed spectrum bands are not efficiently utilized.
- Federal Communications Commission (FCC) in the US has recently decided to open up the TV spectrum for unlicensed use, as long as the licensed users' communications are protected.
- Microsoft has already built a testbed over its Redmond campus to demonstrate the practicality of such sharing

Problems related to Dynamic Spectrum Management

- The regulators need to provide enough economic incentives for the license holders to open up spectrum for sharing, otherwise complicated legal issues might arise.
- What kind of services and commercial business models can succeed in the newly open spectrum bands, considering the potentially unregulated interferences among multiple unlicensed service providers.

Wireless Technologies & Users' Needs

- Wi-Fi technology provide a speed of hundreds of Mbps: good enough even for high definition video streaming – BUT - very limited coverage (e.g., from 20 to 200 meters for indoor communications).
- Cellular network: has the potential to provide seamless access and mobility solutions.
- 4G cellular networks can provide a theoretical peak download speed of 100 Mbps, although the actual speed can be less than 10% of the theoretical one.
- Sophisticated smartphones and tablets: users have significantly higher needs to enjoy high quality and highly interactive content on-the-go.
- Example: to stream a high quality video, Netflix recommends a data rate of at least 5Mbps - BUT - an always smooth playback requires the data rate to be much higher.
- Applications like these make the current cellular network very stressful.
- AT&T networks in big US cities such as New York City and San Francisco often have experienced heavy congestion and low achievable data rates during the past several years
- AT&T introduced iPhone on their networks from 2007 - during the Christmas season of 2009, AT&T even tentatively stopped selling iPhones in New York City, and many suspected that it was due to AT&T's fear of not being able to support the fast growing population of new iPhone users.
- Technology advance alone is not enough to resolve the tension between the supply and demand in the wireless market even in the long run.
- Very important to use economics to guide the operation of the market.

Economics & Wireless Technologies

- Economics of wireless networks: quite different from economics of other industries, due to the unique characteristics of the wireless technologies and applications.
- Economics strongly coupled with the wireless technologies.
  - Wi-Fi technology can provide high data rates within a short distance
  - Cellular technology provides much better coverage with a much lower data rate.
  - The economic models for these two technologies are thus very different.
  - Commercial Wi-Fi providers charge users based on connection time lengths
  - Cellular service providers charge users based on their actual data usage
- Wireless applications: each application/user has a unique
  - Quality of Service requirement
  - resource implication on the networks
  - sensitivity to price.
  - Examples: a video streaming application requires a wireless connection that supports a high data rate and stringent delay requirements. High price for such an inelastic application. Providing a videos streaming application with a data rate higher than needed will not be useful.
  - A file transfer application can adapt to different transmission speeds, but requires a very low bit error rate to ensure correct decoding. Very sensitive to price, and can be arranged to be delivered when the network is not congested and the delivery cost per bit is low.

Deregulation of Telecommunication Markets

- The deregulation of telecommunication markets in many countries has made the study of wireless network economics more important than ever.
- ***Past***: only one major wireless service provider enjoying the monopoly status in a particular local (or national) market.
  - AT&T in the US, China Mobile in China, and Telcel in Mexico.
- ***Nowadays***: several major players in a single market.
  - AT&T, Verizon,T-Mobile, and Sprint in the US, China Mobile, China Unicom, and ChinaTelecom in China.
- Wireless service provider: a profit-maximizing entity needs to optimize the technology choices and pricing mechanisms under the intense market competition.
- Industry deregulation also brings more choices to the wireless consumers.
  - A user may freely compare and choose services from different service providers based on the service quality and cost.
  - A user may even use different service providers for different types of services
  - A service provider may no longer have complete control of its subscribers.

Wireless Network Economics vs Internet Economics (1/2)

- The characterization of network resources in wireless networks is more difficult than in wireline networks.

1. Wireless spectrum can be measured in hertz, but the network resource corresponding to each hertz of spectrum is not easy to characterize.
   - The wireless data rate is highly stochastic over time due to shadowing, fading, and mobility.
   - The wireless resource is spatially heterogeneous, and the same spectrum may be concurrently used by multiple users who are physically far apart without affecting each other.
   - The wireless data rates are affected by mutual interferences. Second, the characterization of end users can be more complicated in wireless networks.
2. A wireless user may have many different attributes, such as utility function, total energy constraint and energy efficiency, and channel conditions. Users' performances are tightly coupled due to mutual interference.

Wireless Network Economics vs Internet Economics (2/2)

3. The interactions between wireless users heavily depend on the specific choice of wireless technology.
   - Random medium access protocols such as the slotted Aloha: users are coupled through their channel access probabilities.
   - Code Division Multiple Access (CDMA) network: users are coupled through mutual interference.
   - Spectrum overlay in cognitive radio networks: unlicensed users cannot transmit simultaneously with the licensed users in the same channel at the same location.
   - Spectrum underlay cognitive radio network: unlicensed users are allowed to transmit simultaneously with the licensed users, as long as the total unlicensed interference generated at a particular licensed receiver is below an interference threshold.

➡ Different interactions and couplings between users lead to different types of markets and economic mechanisms.

4. The coupling between technology, policy, and economics is different in wireless networks.
   - Many wireless technologies can only work under the proper policy framework together with the right economic mechanisms that incentivize all parties involved.